TABLE 2

Individual and Total Current Harmonics

| Data Center Loads | Amps (3-Phase) | Amps (3-Phase) at 480 V | Existing (FIG. 1) harmonics Amps | Individual THD-I % | Passive Filter (FIGS. 2, 3, 6) harmonics Amps | Individual THD-I % | Hybrid Filter:1 (FIG. 8) harmonics Amps | Individual THD-I % | Hybrid Filter: 2 (FIGS. 9, 10) Harmonics Amps | Individual THD-I % | Active Filter (FIG. 11) Harmonics Amps | Individual THD-I % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IT racks | 3084 | 1336 | 468 | 35 | 164 | 12 | 70 | 5 | 70 | 5 | 40 | 3 |
| Evaporator cooling devices | 174 | 76 | 26 | 35 | 9 | 12 | 4 | 5 | 4 | 5 | 2 | 3 |
| CDUs | 30 | 30 | 11 | 35 | 4 | 12 | 4 | 12 | 2 | 5 | 2 | 7 |
| Pump Skid | 30 | 30 | 10 | 35 | 4 | 12 | 4 | 12 | 2 | 5 | 2 | 7 |
| Fluid Cooler | 50 | 50 | 18 | 35 | 18 | 35 | 18 | 35 | 8 | 15 | 10 | 20 |
| Chiller | 320 | 320 | 112 | 35 | 39 | 12 | 39 | 12 | 17 | 5 | 22 | 7 |
| Total Fundamental Amps | | 1842 | | | | | | | | | | |
| Total Harmonics (Amps) | | | 645 | | 237 | | 138 | | 102 | | 79 | |
| % THD-I at Grid | | | | 35 | | 13 | | 8 | | 6 | | 4 |
| Comments | | | L at MV Grid | | $L_M$, effective $L_S$ and additional line reactors for other loads | | $L_M$, 15% AF at LV and additional line reactors for other loads | | 15% AF at MV, effective $L_S$ and additional line reactors for other loads | | 20% AF at MV, 15% AF at LV and additional line reactors for other loads | |

**[0064]** Table 2 shows that a total of 1842 amps of 3-phase fundamental current are needed for a 1 MW DC block at 480 V. The existing electrical system of FIG. **1** with a 5% line reactor L at MV generates a total of 645 amps of harmonic current. With a 5% impedance line reactor, the maximum achievable current distortion level is 35%. Therefore, the total harmonic distortion current (THD-I) at the grid is 35%. The THD-I for IT server racks is also 35%. According to the IEEE 519 standard, the maximum allowed THD-I limit is 8%.

**[0065]** The total harmonic distortion (THD) is the amount of distortion, i.e., the second and greater harmonics, in the current or voltage waveform with respect to the fundamental, i.e., the first harmonic, current or voltage waveform. The total harmonic current distortion (THD-I) is defined as:

$$\text{THD-I}=I_{Total\ Harmonic}/I_1 \quad (3)$$

where $I_{Total\ Harmonic}$ is the total harmonic current and I1 is the fundamental current, i.e., the first harmonic current.

**[0066]** To improve THD-I further, another 5% effective line reactance $L_s$ (either independent or coupled PDU) is added before the IT server and evaporative cooling device loads as shown in FIGS. **2**, **3**, and **6** at the LV side and additional 5% individual line reactors are added for CDU pump-motor VFDs, pump skid pump-motor VFDs, and chiller module compressor-motor VFDs. The electrical system also includes a 5% line reactor $L_M$ at the MV side in addition to the above added filters. This is part of passive filtering techniques. The combination of all the above filters generates 237 A of harmonic current. Therefore, the total harmonic distortion current (THD-I) at the grid is 13%, which is lower in comparison to the THD-I of FIG. **1**. The THD-I for the IT server racks is 12%.

**[0067]** The hybrid filtering technique is implemented to further improve the THD-I. For example, in the hybrid filtering technique implemented in FIG. **8**, both passive and active filtering are performed. In addition to the 5% compensation provided by the line reactor $L_M$ at MV, the hybrid filtering technique implemented in FIG. **8** also provides active filtering having a 15% compensation capacity for IT servers and evaporative cooling devices. There are also 5% individual line reactors for CDU pump-motor VFDs, pump skid pump-motor VFDs, and chiller module compressor motor VFDs. The combination of all the above compensation components generates 138 amps of harmonic current. Therefore, the total harmonic distortion current (THD-I) at the grid is 8%, which satisfies the IEEE 519 standard and is lower than the THD-I of the electrical systems of FIGS. **2**, **3**, and **6**. The THD-I for the IT server racks is 5%.

**[0068]** In the hybrid filtering techniques implemented in the electrical systems of FIGS. **9** and **10**, both the active and passive filtering are performed. In addition to the15% compensation capacity provided by the MV active filtering technique, the hybrid filtering techniques implemented in the electrical systems of FIGS. **9** and **10** also provide 5% compensation from the line reactor $L_S$ at the LV side for the IT servers and evaporative cooling devices. There is also 5% compensation capacity provided by the individual line reactors for the harmonics introduced by the CDU pump motor VFDs, the pump skid pump motor VFDs, and the chiller module compressor motor VFDs. In sum, the hybrid filtering techniques implemented in the electrical systems of FIGS. **9** and **10**, generates 102 amps of harmonic current. Therefore, the total harmonic distortion current (THD-I) at the grid is 6%, which is lower than the maximum limit specified by the IEEE 519 standard and is lower than the THD-I of FIG. **8**. The THD-I for the IT server racks is 5%.

**[0069]** To achieve lower THD-I, active filtering techniques for both MV (20% capacity) and LV (15% capacity) may be employed. There are also 5% individual line reactors